DESIGN AND ANALYSIS OF URBAN CAR FOR SHELL ECO MARATHONS ASIA

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ABSTRACT

Shell Eco Marathon Asia is a competition based on car race, which requires the participant to design and fabricate the most fuel saving cars. There are two categories being promoted, which are prototype and urban car type. The team representative in this category known as the SAE - UMP Chapter is taking the challenge and builds up the urban car for the 2010 events at the Sepang International circuit, Malaysia. For that year, the team has won the third place in urban category. Since then, various improvements have been carried out by the team to compete for the top 3 position and create the most efficient car ever build in Universiti Malaysia Pahang. This thesis focuses on improvement of existing model in terms of aerodynamics. Aerodynamic is an important area of study as it relates to parasitic load experienced by the engine. The objective of this project is to design fives new model with the improved drag coefficients compared to existing models and finally to select the best design in terms of the aerodynamic features. The CFD analysis was performed by using Flow Simulation in Solidworks with standard condition where air density equal to 1.184 kg/m^3 and at 1 atm environment pressure. The relative velocity of the analysis varies from 40 km/h to 90 km/h due to the minimum allowed velocity and maximum capable velocity of the car on track. The result of simulation shows that model 2 has the minimum drag coefficient which is equal to 0.281 and has improved the *Cd* by 37% compared to existing models. In this analysis, the most aerodynamic body is the one with minimum drag coefficient, minimum aerodynamic power and minimum relative pressure over the wake region. In selecting the model, the method of the Spider-web graph plot was used to visualize the widest area covered by the model in parameter axis. At the end of the analysis, model 2 shows the widest area covered in the graph plot which by quantitative measure, model 2 has the minimum drag coefficient, minimum aerodynamic power and minimum relative pressure over the wake region in the environment among the other 4 models.

ABSTRAK

Shell Eco marathon Asia ialah satu pertandingan berbentuk perlumbaan kereta yang memerlukan peserta untuk mereka dan membina kereta yang menjimatkan pengunaan bahan api. Terdapat dua kategori yang dipertandingkan iaitu kategori prototaip dan kategori urban. SAE-UMP Chapter telah menyahut cabaran tersebut dan bertanding untuk kategori urban dan telah memenangi tempat ketiga di Litar Antarabangsa Sepang, Kuala Lumpur. Sejak dari itu, pelbagai penambahbaikkan telah di lakukan bagi membolehkan kumpulan dari universiti pantai timur ini menduduki tempat ketiga teratas lalu membina kereta pertama di Universiti yang menjimatkan minyak. Tesis ini ditulis bertujuan menerangkan salah satu metod penambahbaikkan kereta dari segi aerodinamik. Objektif projek ini ialah membina lima buah model berdasarkan syarat pertandingan dan memperbaiki ciri aerodinamik kereta berbanding model kereta yang sedia ada terutama dari segi pekali geseran. Analisis CFD telah dilakukan dengan menggunakan Simulasi Aliran menggunakan perisian Solidworks dalam keadaan standard di mana ketumpatan udara sama kepada 1.184 kg/m^3 dan tekanan persekitaran pada 1 atm. Halaju relatif analisis berbeza dari 40 km/j hingga 80 km/j berdasarkan halaju minimum yang dibenarkan.Keputusan simulasi menunjukkan model 2 mempunyai pekali seretan yang minimum iaitu sama dengan 0.281 dan ia lebih rendah nilainya sebanyak 37% berbanding dengan model yang sedia ada. Dalam analisis ini, model yang paling aerodinamik ialah model dengan pekali seretan yang minimum, kuasa aerodinamik yang minimum dan tekanan relatif yang minimum . Dalam memilih model, kaedah plot Spider-web digunakan untuk menggambarkan kawasan yang paling luas yang diliputi oleh model dalam paksi parameter berdasarkan pemberat. Penghujung analisis menunjukkan, model 2 punyai kawasan yang paling luas yang diliputi dalam plot graf, dengan erti kata yang lain model 2 mempunyai pekali seretan minimum, kuasa aerodinamik yang minimum dan tekanan relatif yang minimum pada bahagian belakang model berbanding model-model kereta yang lain.

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A_f	Frontal area
a	Tunnel wide
b	Tunnel height
C_d	Drag coefficient
$C_{d(avg)}$	Average drag coefficient
C_l	Coefficient of lift force
d_h	Hydraulic diameter
F_d	Drag force
$F_{d(avg)}$	Average drag force
F_l	Lift force
L_e	Entrance length
ΔP	Relative pressure
P_w	Wake pressure
P_e	Environment pressure
P_a	Aerodynamic power
Re	Renault number
v_r	Relative velocity
v	Velocity
ρ	Fluid density
μ	Fluid dynamic viscosity

LIST OF ABBREVIATION

SEM Asia	Shell Eco Marathon Asia
SI	Standard International unit
CFD	Computational Fluid Dynamics
3D	Three dimensional
CAD	Computer Aided Design

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

This chapter basically discusses about the upper design of the urban car body proposed. Currently, urban areas suffer heavily from problems caused by the excessive use of the private car which also cause the congestion to air and noise pollution. Urban transport is not only a significant contributor to climate change, but also the main source of fine particulate matters. The pollutant may cause many cities in the world to exceed the thresholds given in the world air quality directive. One of the solutions that can be made is using an urban concept car. The urban concept car is a car designed to be used in city traffic. It is normally small in size and not design to run fast, but very fuel efficient. Urban cars are often hailed as the answer to the escalating levels of air pollution and traffic congestion that result from increases in numbers of larger personal vehicles. They are intended for use exclusively in or near cities and towns, but they are not suited to long journeys or fast travel on highways. They are very light, pollute little, take up a fraction of the space required by most vehicles, cost much less than most cars and trucks, and can be effectively recycled, Erdmenger and Fuhr, (2005).

This work intends to study the aerodynamic of the urban car`s. Moving object tend to be opposed by the existence of the air. This resistance varied with the ambient temperature and altitude from the sea level. The magnitude of the resistance is measured in term of drag force. The drag force of the moving car is supplied by the surface contact of the tire to the road, the drag force created on the car body surface and the pressure drag happened in the rear of the car. An object that was designed to develop minimum drag force is happened to be aerodynamic. When the drag force is reduced, the power from the engine to overcome this resistance is less and certainly used less fuel. Thus it is important to study what is the engineering approach that can be develop upon the car so that it will be aerodynamic and eventually create minimum drag force.

1.2 PROBLEM STATEMENT

Shell Eco Marathon Asia is a competition based on car race, which requires the participant to design and fabricate the most fuel saving cars. There are two categories being promoted, which are prototype and urban car type. The team representative in this category known as the SAE - UMP Chapter has took the challenge and builds up the urban car for the 2010 events at the Sepang International circuit, Malaysia. For that year, the team has won the third place in urban category. Since then, various improvements have been carried out by the team to compete for the top 3 position and create the most efficient car ever build in Universiti Malaysia Pahang. The existing model however do not obey the principal of streamline which significantly contributed to drag force. This thesis focuses on improvement of existing model in terms of aerodynamics. Aerodynamic is an important area of study as it relates to parasitic load experienced by the engine. The Shell Eco marathon is about to promote a car that runs with minimum fuel consumption.

1.3 OBJECTIVES

The main objective of this project is first to design fives model of urban car concept which is an improvement of existing model base on Shell Eco marathon Asia`s rules. The secondary objective is to analyze the aerodynamic features of the models and lastly to justify the best design based on required aerodynamic feature.

1.4 PROJECT SCOPES

This project consists of three main scopes that guide the project progress so that it get linear with the objectives. Firstly, the previous urban car design will be studied particularly in the shape of the body. The body of the car will be developed in Solidworks so that its drag coefficient can be obtained. After that, new five models will be developed in the same software and the drag coefficient is being analyzed. Among the fives design, there will be one design that will be chosen and that model is an improvement of the previous design in term of drag coefficient. The scope of the project can be summarized as follows;

i Focus on a development of 1-seated urban car body which consists of studying and designing of a 1-seated urban car

ii. Develop 3D models of the previous car body into Solidworks and perform CFD analysis using Flow Simulation to obtain drag coefficient.

iii. Configure the body shape of the car in term of size, dome angle, frontal area and apply those onto five new models to see the trend of aerodynamic drag.

iv. Perform computational fluid dynamic analysis to each design to obtain lowest drag coefficient.

v. The analysis of aerodynamic is focused on drag coefficient, drag force, aerodynamic power and relatives wake pressure and environment pressure

vi. Justify the best design based on aerodynamic feature.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

This chapter briefly discusses about the study regarding analysis upon an upper body design for Shell Eco marathon competition in the urban car category. At first, the chapter discusses about the Shell Eco marathon Asia competition. This chapter then followed by a brief explanation regarding the urban car concept. Then, this chapter delivers the theory of aerodynamics of the ground vehicle. The section discusses about the official rules of the competition which is the most important part in considering the design configuration. As for the analysis, the review is about the significant of using Computational Fluid Dynamic analysis instead of a wind tunnel to determine the drag coefficient of the model.

2.1 INTRODUCTION TO SHELL ECO-MARATHON ASIA

Shell Eco-marathon challenges high school and college student teams from around the world to design, build and test energy efficient vehicles. With annual events in the Americas, Europe and Asia, the winner is the team that goes furthers distance using the least amount of energy. This event also affords an outstanding engagement opportunity for current and future leaders who are passionate about finding sustainable solutions to the world’s energy challenge. There are two categories contested; urban category and prototype category. For this year, Malaysia hosts the stages for the third and the last time. This project reports however proposing the design of the urban car concept for the competition. The specific goal of the competition defines how the upper design of this concept car. On the other hand, the upper design is limited by rules and regulation as published by Shell in their official website. Basically the challenge is about to reduce the consumption of fuels as far as it goes. Understanding of how the upper car design helps to achieve this objective is the main issues in this report. As the car moves, the engine has to oppose the static air around the body. However, the body shape that is designed to streamline will reduce the power to overcome this static air and consequently allowing the flow of it through the body. This competition was an inspirational effort in order to promote automotive engineering and alternative fuel among the students. The lists of the winner from Asia level are shown in Table 2.1. It may not intrude into popular races of Formula One but with the competition leveling the technology achievements around the globe.

Table 2.1: Winners of Shell Eco Marathon Asia for 2010 and 2011 event`s

Place (Urban car)	Fuel type	Events 2010
1st	Hydrogen	NUS Urban Concept (Singapore). 612 km/l
2nd	Gasoline (Petrol)	MESIN ITS (Indonesia). 238km/l
3rd	Gasoline (Petrol)	Zamrud Khatulistiwa (Indonesia). 62km/l
4th	Gasoline (Petrol)	Yellow Makara (Indonesia). 54km/l
5th	Gasoline (Petrol)	UMP SAE Team (Malaysia). 39km/l.
Place (Urban car)	**Fuel type**	**Event 2011**
1st	FAME	MESIN ITS 4 (Indonesia). 150km/l
2nd	Gasoline (Petrol)	Cikal Nusantara (Indonesia). 117km/l
3rd	Gasoline (Petrol)	MESIN ITS 3 (Indonesia). 113km/l
4th	Gasoline (Petrol)	SEMART 2 (Indonesia). 71km/l
5th	Diesel	Team Up (Philippines). 60km/l

Source: http://www.shell.com/home/content/ecomarathon/results

2.2 CAR IN URBAN AREA

A city car (or urban car) is a small car intended for use primarily in an urban area. Mostly, this urban type car was invented using alternative fuel such as hybrid technology, fuel cell, electric powered system etc. This is on purpose to reduce the pollution in the urban area. According to Keiko Hirota in his article “Comparative Studies on Vehicle Related Policies for Air Pollution Reduction in Ten Asian Countries, (2010)”, the contribution of carbon dioxide in Malaysia was 98 % discharged by automobiles. Where 42 % was discharged from passenger vehicles, 39.4 % are from van and lorries (truck) and 14.7 % was discharged from the motorcycle as recorded by the Department of Environment, (2004)

As the population increase it is important to keep the eco-system balance between the living thing and urbanization. Due to the approach of eco-friendly, the modern car was designed to be more efficient and fuel saving. Aligned with the concept of aerodynamics, the shape is likely to be rounded, small and lightweight. Technically, urban car is widely used in urban area.

Apart from addressing the concern of society for environmental protection and energy conservation through upper body design, the power system of the car also being developed such as hybrid vehicles. According to J. Y. Wong, 2008; the term ’hybrid-drive’ is used to denote a drive system consisting of two or more types of power source to propel the vehicle, such as a combination of the internal combustion engine and the battery powered electric motor, or a combination of the fuel cell and battery to power the electric drive. The example of hybrid car is shown in Fig. 2.1

Figure 2.1: The ‘Riversimple’, a hybrid car

Source: http://www.popsci.com/hybrid car

2.3 THEORY OF AERODYNAMIC

2.3.1 Parameters of aerodynamic drag

This study is concerned with the drag force that exerted upon a moving ground vehicle. There is a study known as Automotive Aerodynamics where it emphasized on the aerodynamics of road vehicles. The main concerns of automotive aerodynamics are reducing wind noise, minimizing noise emission, and preventing undesired lift forces and other causes of aerodynamic instability at high speeds. Basically, the drag force or resistance of the aerodynamic denoted as F_d, is governed by several parameters that value the level of efficiency of the car. In practice, the aerodynamic resistance is usually expressed in the following form (Theory of Ground Vehicle, J. Y. Wong, 2008);

$$F_d = \frac{1}{2} C_d \rho A_f v^2 \tag{2.3.1}$$

where,

F_d : Drag force, N

ρ : Fluid density, kg/m³

C_d : Drag coefficient

A_f : Frontal area, m²

V_r : Relative velocity, m/s

Aerodynamic resistance is proportional to the squared of velocity. Thus the power used to overcome the aerodynamic drag increase with the cube of the velocity. Aerodynamic condition affected by the air density ρ, and hence aerodynamic resistance. An increase in ambient temperature from 0 ℃ to 38 ℃ will cause a 14 % reduction in aerodynamic resistance, and increase in altitude of 1219 m will to decrease to resistance drag by 17 %. However the significant effects of ambient conditions on aerodynamic resistance can be neglected in this study as we are not interested to manipulate the altitude. The moving vehicle will produce the distribution velocity that's created skin friction due to viscous boundary layer which acts as tangential forces (shear stress) and eventually contribute to drag.

The improvement in the characteristic related through the drag force is ruled by Bernoulli Equation. Basic assumptions of Bernoulli's Equation for an air flow are viscous effects that are assumed to be negligible, the flow is assumed to be steady, which assumed to be incompressible and the equation is applicable along streamlines.

$$P = \frac{1}{2}\rho\, v^2 \tag{2.3.2}$$

where,

P : Pressure, kPa

ρ : Fluid density, kg/m³

v : Velocity, m/s

In an incompressible fluid flow experiment, equation (2.3.2) used to relate the parameter of pressure and velocity of the fluid. From the equation above it shows that the increasing of velocity will cause the decrease in static pressure and vice versa. In relation to force distribution of a moving car, the force due to pressure differential along the body surface created a perpendicular resultant force that contribute both lift and drag forces.

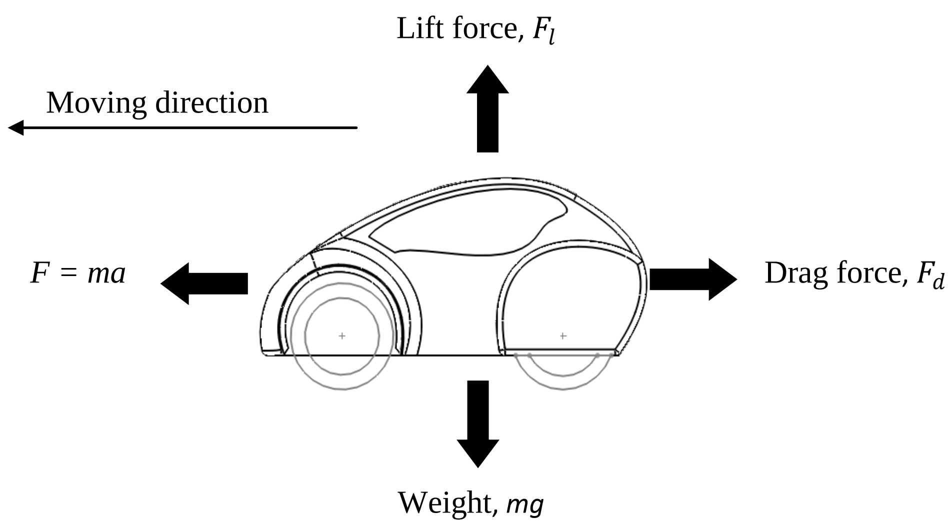

Figure 2.2: Component of force of a moving car.

However there are two components that contribute to total drag of a moving vehicle. The first one is the drag that was created along the body due to viscosity effect and is called drag force while the other one is the pressure drag which is due to the low pressure created at the rear of the body as shown in Fig. 2.3. The other component, directed vertically, is called the aerodynamic lift. It reduces the frictional forces between the tires and the road thus changing dramatically the handling characteristics of the vehicle. In addition to geometry, lift, F_l is a function of density, ρ and relative velocity, v_r. Lift is the net force (due to pressure and viscous forces) perpendicular to flow direction. The aerodynamic lift force is defined as follows.

$$F_l = \frac{1}{2} C_l \rho A_f \, v^2 \tag{2.3.3}$$

where,

F_l : Lift force, N

ρ : Fluid density, kg/m³

C_l : Lift coefficient

A_f : Frontal area, m²

v_r : Relative velocity, m/s

Aerodynamic lift and its proper front-and-rear-axle distribution is one of the key aspects in terms of on-road stability. As long as driving speed is low, below say 100 km/h, lift and pitching moment have only a small effect on the directional stability of a car, even in crosswinds. However, at higher speeds this is no longer true.

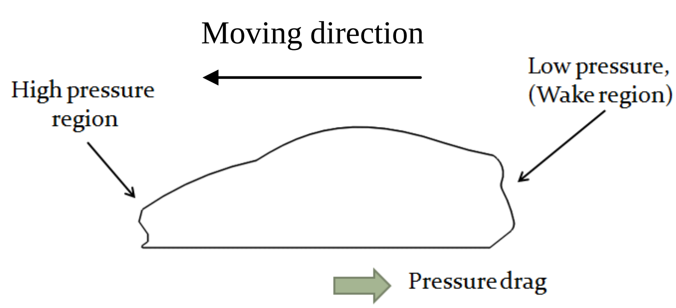

Figure 2.3: Pressure drag created in the wake region.

Some cars are designed with short tailed to comply with the compact mode. This can be seen clearly in urban car feature. The fact is the cut –off rear profile of the car create high changes of turbulent flow. As for the result, the air flow velocity is increased and consequently creates low pressure. This region is called wake region where the pressure is much lower compared to environmental pressure. The differential value of the pressure will trigger resultant force that opposed the motion of the car. The equation of resultant pressure expresses as follows;

$$\Delta P = P_e - P_w \tag{2.3.4}$$

where,

ΔP **:** Relative pressure, kPa

P_w **:** Wake pressure, kPa

P_e **:** Atmosphere pressure, kPa

Drag is considered as a parasitic load that reduces the performance of the engine. The aerodynamic power visualize the magnitude of power require to overcome the drag. The drag force affects the engine performance but the value does not correlate with the engine measurement. The power required to overcome the drag force is given by:

$$P_a = F_d \cdot v \tag{2.3.5}$$

where,

P_a : Aerodynamic power, kW

F_d : Drag force, N

v : Velocity, m/s

2.3.2 Implementation to improve aerodynamic feature

With growing emphasis on fuel economy and on the reduction of undesirable exhaust emissions, it has become increasingly important to optimize vehicle power requirements. To achieve this, it is necessary to reduce the aerodynamic resistance (drag), rolling resistance and inertia resistance. According to J. Y. Wong (2008), the aerodynamic resistance is generated by two sources: one is the air flow over the exterior of the vehicle body, and the other is the flow through the engine radiator system and the interior of the vehicle for purposes of cooling, heating, and ventilating.

The external air flow generates normal pressure and shear stress on the vehicle body. According to the aerodynamic nature, the external aerodynamic resistance comprises of two components, commonly known as pressure drag and skin friction. The pressure drag arises from the component of the normal pressure on the vehicle body acting against the motion of the vehicle, while the skin friction is due to the shear stress in the boundary layer adjacent to the external surface of the vehicle body. On the two components pressure drag is by far the larger, and constitutes more than 90% of the total external aerodynamic resistance of a passenger car with normal surface finishing (J. Y. Wong, 2008). Reducing aerodynamic drag is important for improved fuel consumption and higher top speed for a given power as shown in Fig. 2.4. The following is the regular way to approach aerodynamic drag reduction for land vehicle (Kalm, 2007).

i. The ground-up approach where the main body is shaped for low drag and then the non-aerodynamic element is designed within the body constraint.
ii. The improvement approach where the designer starts with the vehicle that already satisfies non aerodynamic constraint and finesses the detail to lower the drag as much as practical.

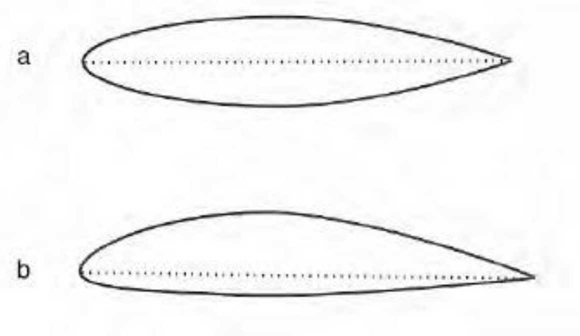

Figure 2.4: The shape of body (a) tear drop body, (b) aerofoil body

Source: Jaray and Klemperer (1920)

The first known streamlined land vehicle was developed by Jaray and Klemperer, (1920). They have discovered that, though an asymmetric teardrop body has the lowest drag in free air, as the body is brought closer to the ground, the drag force increases tremendously. For example, in the ground clearance found in automobiles, the drag force of the torpedo shape can be increased 50 %. If the ground clearance is zero, the drag force of the torpedo shape can be increase into almost 500 %. To preserve the robustness, Jaray and Klemperer invented the solution by chambering the body. To chamber the body, the belly can flattened or the top side of the body can be arched higher as in Fig. 2.4. b ,Kalm, (2007).

Around 1980`s, a professor of the Turin Technical University (Italy), Professor A. Morelli investigated whether it was possible for basis body near to the ground having an equivalent drag to the streamlined body in free air as shown in Fig. 2.5. The Morelli body achieved the minimum drag coefficient, based on frontal area under 0.05, matching that streamlined bodies are free air (Kalm, 2007)

Figure 2.5: Morelli streamlined car.

Source: Kalm, (2007)

The motion of the car on the ground introduces problems which differ greatly from those of an aircraft, primarily because of interference with the airflow between the car underside and the ground. That is because the car moves very closely to the ground this interference is one of the most important features of the airflow pattern around it. In many cars the underneath of the engine compartment is open to the ground to improve the cooling of the engine's crankcase. This cavity is formed full of structural or suspension members which may produce flow separation just behind the front bumper. Air inside this cavity is usually affected by the front grille and the high dynamic pressure region in front of the vehicle. This helps to create an additional aerodynamic lift force. Most of the car has a rough underside. The average roughness is ± 15 cm (or 6 inches) considered from a main surface level. According to A. J. Scibor-Rylski, (1984), airflow between the underside and the ground is however affected by the distance between the underside and the ground, the width, length and height ratio of the vehicle and the styling of the body shape, the roughness of the underside, and the lengthwise and crosswise curvature of the underside panel.

In a line at which the separation would be inevitable due to viscous friction, the shape is "bobtailed" as shown in Fig. 2.6. According to A. J. Scibor-Rylski, (1984), bobtailed the rear of the car reduces the size of wake region. The small size of the wake